The Corn and Climate Report

An overview of climate science
in the service of Midwestern agriculture

Executive Summary

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US Climate Change Science Program
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NORTH CENTRAL BIOECONOMY CONSORTIUM
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CLIMATE SCIENCE INITIATIVE

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Introduction

by Gene Takle

Unprecedented pressures are now being exerted on the productive potential and sustainable use of Midwest landscapes. Demands for more food, livestock feed, biobased feedstocks for manufacturing, and biobased alternatives to fossil fuels raise questions about increased production of traditional crops and introduction of new ones. And looming in the background is the prospect of climate change – both within the region and globally. Of particular interest to producers in the Midwest is the prospect for climate change or increased climate variability in regions producing commodity crops similar to those grown in the central US. This region clearly is important to the future of the nation in areas of food security, energy independence, and availability of fresh water.

As climate continues to change in the region – a continued trend toward more frost-free days, possible continued increase in annual precipitation and heavy rainfall events, continued humidity increases—growers will face new challenges with existing crops. And if there is a shift to more acreage planted to crops for the production of biofuels, new crop-climate learning curves will be launched. Both scenarios call for more dialogue between producers and weather/climate service providers.

Producers and agribusiness providers in the region are known for their early adoption of sophisticated technology. GPS-guidance is used for managing tillage, planting, inputs, and harvesting operations, and specialized monitoring and forecasts are used for irrigation scheduling. Improvements in satellite observing systems to include soil moisture are forthcoming, and recommendations have been made for major expansion in nation-wide surface observing networks, including in-situ soil moisture measurements in every county (Carbone et al., 2009).

Three time-scales are considered important to agriculture and also to climate science: 0-10 days, 10 days to 2 years, and 2-30 years. The near term is considered important for timing of agricultural operations; meteorological information for the near term is provided from weather forecast models that provide predictions at 1 to 6 hour intervals, with skill declining to near zero beyond about 7 days. The intermediate (seasonal to interannual) time scale is important for agricultural purchases of inputs (seed, herbicides, fertilizer) and marketing; climate information for the intermediate term is supplied by statistical models based on slowly changing factors such as El Niño, La Niña, the North Atlantic Oscillation or by use of global and regional climate models. In the long term, producers decide on land purchases, conservation practices, construction of storage facilities, etc.; climate information for these time scales is provided by global and regional climate models.

Uncertainty is a hallmark of weather and climate information on all time scales. Quantifying uncertainty and enabling informed decision-making under various challenges that require more intense dialog between providers and users of weather and climate information. Development of commonly understood technical terms, use of probabilistic models and ensembles of deterministic models, and awareness of the consensus of scientific understanding are key elements of improving decision-making under uncertainty.

The Midwest has several of the nation's largest public universities, including several large land-grant institutions with research, education, and outreach capacity dedicated to serving the agricultural community. The state agricultural extension services, in particular, have vast networks that include trained professionals in every county across the region. This network enables rapid deployment of new information and decision-support tools for use by individual agricultural producers. Web-based delivery of information and products ensures wide access across the region and promotes development of communities of users who feed back experiences to tool developers.

A workshop on the theme of "Corn and Climate" was first envisioned by NOAA's Central Regional Team at a meeting held in Kansas City in November 2007. Workshop Co-Organizer Doug Kluck brought the idea to the attention of ISU and organizers of the annual "Growing the Bioeconomy" Conference in April 2008. He, along with Workshop Co-organizer Don Mock Executive Director of the NOAA Research Laboratories, helped recruit the high quality slate of presentations you see in this document. This workshop was an attempt to bring providers of weather and climate services (NOAA) together with producers, agribusiness providers, and advisors from state agriculture extension services to assess the latest scientific understanding of climate, climate variability, and climate change of the Midwest. The agenda was specifically designed to both provide the latest information in climate science and allow for discussion on possible new uses of climate science for agricultural decision-making.

In assembling this workshop summary we have made efforts to create a highly readable document for the non-specialist. The workshop itself was a collection of presentations by specialists from a variety of areas but presented informally with a lot of spirited discussion. We have attempted to capture this collegiality and upbeat interaction in the workshop summary. Our hope is that we have opened the door to more intense dialog among agricultural producers and weather/climate service providers. National investments in weather and climate observations and forecasting will not reach their full potential without strong and thoughtful feedback from the users of these services. To facilitate such ongoing dialog we provide contact information and encourage readers to get in touch with the organizers and presenters.

Finally, I must emphasize that this workshop and report would not have been possible without the very dedicated work of the Jill Euken, Deputy Director of Bioeconomy Institute at Iowa State, the Scheman Conference Center staff, and the staff from the Great Plains Institute. Jill's unique skills at coordinating the details of the Workshop from its inception, while concurrently organizing the Bioeconomy Conference held the previous two days, were truly amazing. Julie Kieffer, ISU Scheman Center Conference Planning and Management, ensured that our needs for food and technical equipment were met

Climate changes mean agricultural changes

As climate continues to change in the region – a continued trend toward more frost-free days, possible continued increase in annual precipitation and heavy rainfall events, continued humidity increases – growers will face new challenges with existing crops.

at the Scheman Center. Floyd Davenport, Information Technology Officer for ISU Extension, oversaw the videotaping of the individual talks and posted all on the web.

Under the able leadership of Program Director Brad Crabtree, the Great Plains Institute's Program Manager Brendan Jordan and Program Associate Sarah Wash joined the NOAA and ISU members of the organizing team for several conference calls during the planning stages that led to the overall concept of this unique workshop summary. With Sarah's oversight and transcription help from Megan Hassler, intern at the Great Plains Institute, we were able to turn videotapes into this workshop summary in a remarkably short time.

To all these who helped make this event a success, including the presenters and Workshop participants, we offer our heartfelt thanks.

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References:

Carbone, R. E., J. Block, G. R. Carmichael, F. H. Carr, V. C. Chandrasekar, E. Gruntfest, R. M. Hoff, W. F. Krajewski, M. A. LeMone, T. W. Schlatter, E. S. Takle, J. Titlow, S. E. Boselly, J. F. Purdom, 2009: Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs. Natl. Research Council of the Natl. Acad. Sci., BASC, Richard E. Carbone, Ed., National Academies Press. (In Press)

Part 1: Climate science shows that human activity is a dominant factor contributing to climate change

1-1. What is climate science?

Climate science is distinguished from the more general discipline of atmospheric science or meteorology by its emphasis on climate as opposed to weather. Climatology is the study of average conditions over some time period, whereas meteorology is the study of actual events. It has been said that "climate is what we expect, and weather is what we get." Climate science is distinguished from climatology by practitioners in the field by the fact that climate science relies heavily on numerical models for the study of climate processes, whereas climatologists primarily use statistical methods to study climate. Climate scientists also use statistical methods to study the output of their numerical models and to compare these results with observations. The distinction is in the wide use of numerical models by climate scientists. These numerical models (in contrast to, say, statistical models or conceptual models) are based on the fundamental laws of physics and have essentially the same basic equations as models used by fluid engineers to study thermodynamic processes in combustion chambers, flow around airplane bodies, and turbulence in pipes and ducts.

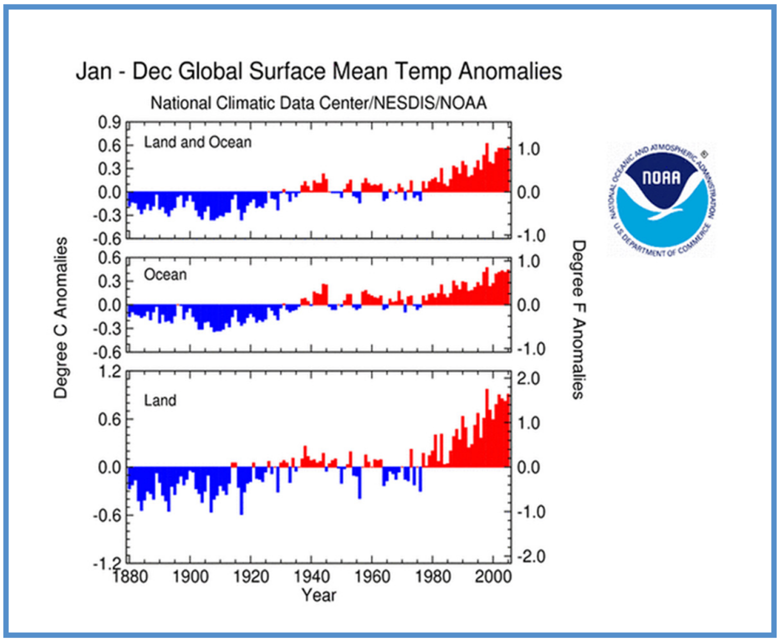


Figure 1. Changes in the Earth's mean surface temperature from 1880 to the present.

Climate scientists use these models

together with all available data to uncover and understand the fundamental physical processes of climate and climate change. Our confidence in the use of these models to develop credible scenarios of future climates continues to improve by the abilities of these models to explain climate conditions and climate changes of the past.

1-2. Global climate change is unequivocal.

Scientists at US federal agencies, universities, and their international counterparts now report with very high confidence that the atmosphere is warming at a rate unprecedented in history. The warming and associated climatic shifts are impacting traditional ways of life for people all over the globe, especially for those whose livelihoods depend on very specific weather conditions. The Corn and Climate Report summarizes the reasons why we now know that the climate is changing, that the release of greenhouse gases into the atmosphere from human activity is a primary driver of these changes, and the potential implications for Midwestern farming communities in the short and long term.

1-3. What causes climate to change?

Two classes of factors, known as climate forcings, cause climate to change: natural and anthropogenic (or human-caused). The list of natural forcings includes volcanoes, variations in output of the sun, and, to a lesser extent, changes in atmospheric ozone concentrations. Individual volcanoes have a very large effect in the short term (1-2 years), typically a cooling effect. Solar variation also has a minor effect on the climate on scales of 5-10 years (sunspot cycles, +/- 0.5 W/m2) and a somewhat larger effect on time scales of 30-100 years (+/-1 W/m2). On scales of 100,000 years, changes in the Earth's orbit around the sun and wobble of the Earth on its axis cause changes in absorption of energy at the Earth's surface of sufficient magnitude to cause ice ages and interglacial warm periods. Anthropogenic forcings include sulfate particles, which have a cooling effect, and greenhouse gases like carbon dioxide and methane, which have a warming effect. Greenhouse gases are what are considered "well mixed," meaning that because of their long lifetimes in the atmosphere, they mix with the air at all levels. It can take a hundred or more years for that extra carbon to be taken out of the atmosphere through natural processes. Unlike greenhouse gases, sulfate particles can be washed out or deposited out to the atmosphere in about two weeks, so they have a more localized effect. Sulfate particles are produced by burning fossil fuels, but they are easily kept out of the atmosphere with pollution control devices commonly used in newly constructed coal-fired power plants. However, not all new power plants in all countries use the latest technology, and the number of coal-fired power plants in operation continues to rise. Therefore, atmospheric concentrations of sulfate particles, and their attendance cooling effect on the climate, continue to rise.

Figure 2. Two photos of Muir Glacier in Alaska. Top photo: 1941, bottom photo: 2008.

1-4. How do we know that the earth is warming?

Surface temperature measurements with thermometers have been made around the world with sufficient density to allow global mean temperatures to be estimated since about 1880. Figure 1 shows the trend in mean global temperatures annually updated by NOAA's center in Asheville, NC from 1880 through 2007.

Measured temperatures alone are not sufficient to confirm with high confidence that the planet is warming. Other indicators such as glacial termini, borehole temperatures, and coral bleaching provide independent evidence of current climate trends. Arctic sea-ice extent, one of the most dramatic indicators, has been

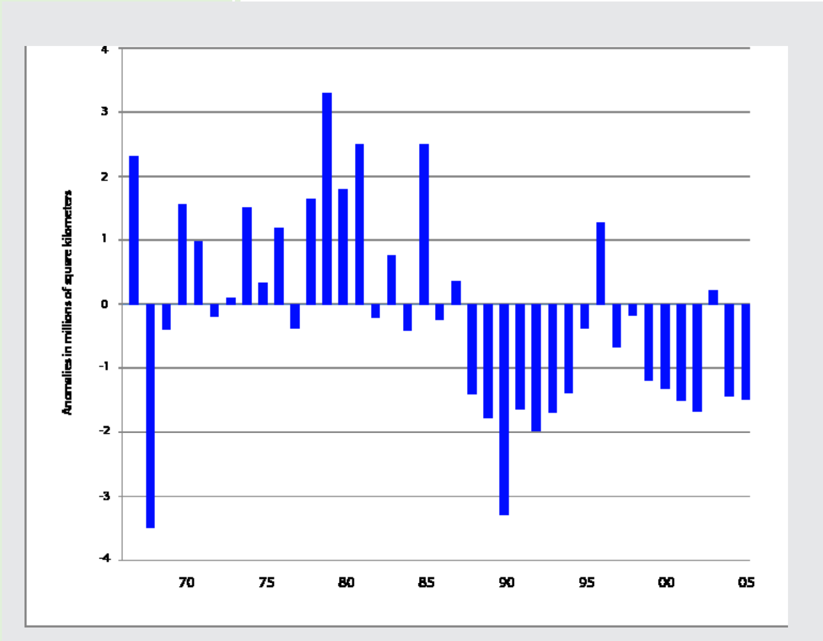


Figure 3a. Measurement of snow cover over North America shows an overall decrease since 1970.

observed to be rapidly decreasing since 1979 – the time that satellites first were able to make such measurements. In 2007 sea-ice extent reached a record low of 4.28 million square kilometers, and in 2008 the minimum was nearly as low. Glaciers are also rapidly declining: Figure 2 shows two photos, taken from the exact same location and angle, of Muir Glacier in Alaska in two different years; the first is 1941, the second is 2008. Additional evidence for warming is provided by the fact that earthquakes on Greenland due to glacier melting have doubled between 2002 and 2005, and global winter snow cover is rapidly decreasing, as shown in Figure 3.

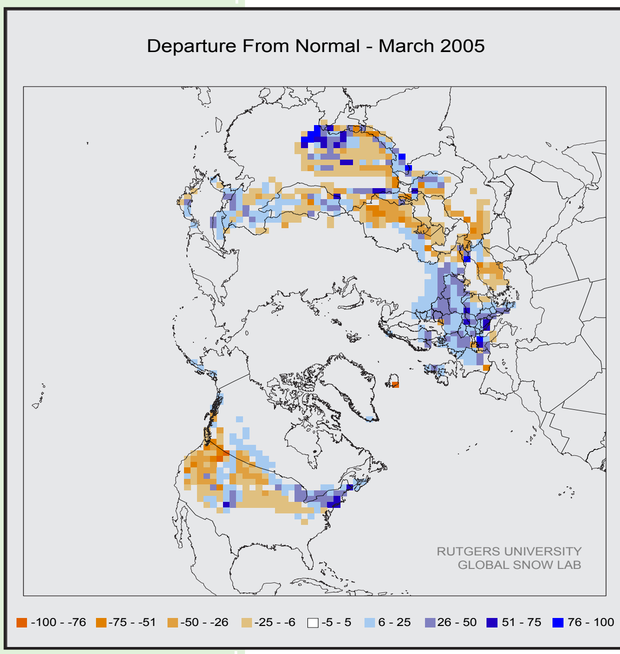


Figure 3b. The Northern Hemisphere has experienced large scale changes in snow cover in the last few years-March 2005 showed large departures from normal, with increases in some areas and decreases in others.

1-5. How do we know that today's warming is being driven by human activity?

The ability of greenhouse gases to trap heat is a well-studied and well-understood scientific fact that can be demonstrated in a simple laboratory experiment. If you have two upside down cylinders and add greenhouse gases to one and not to the other, then put a heat source under both, the cylinder with the greenhouse gases will absorb heat and experience a temperature rise.

We can track the amount of greenhouse gases in the atmosphere over a period of time that extends from tens of thousands of years ago to the present day through something called climate proxies—small air bubbles or pockets trapped in ice in Antarctica or pollens trapped in sediments in lake bottoms. Prior to the beginning of the Industrial Revolution, there were small-scale changes in the amount of greenhouse gases in the atmosphere, but climate scientists have tracked and recorded a rapid rise in the amount of carbon dioxide in the atmosphere that began with the start of the Industrial Revolution—around 1880.

Sometimes climate-change skeptics claim that the excess heat is being absorbed by the ocean and as a result is not changing the climate. We do know that the ocean has been absorbing the heat—about half of the greenhouse-induced heat has been distributed in the top layers of the ocean leading to a steady increase in ocean heat content. There is evidence that all components of the climate system – the land masses, the ocean, the ice masses and the atmosphere—are exhibiting warming.

When scientists talk about climate change, they talk about not only the magnitude of change, but also the rate of change. It is an important distinction to make, because the rate of change provides additional evidence of the underlying cause, and secondly it is the rapid changes in the Earth's climate that will affect people living today. The climate has certainly been warmer in the past—the Eocene Climate Maximum, about 50 million years ago, was so warm that crocodiles could have survived comfortably in northern Canada. But these changes took place over a 20,000-year period, and there was a combination of adaptation and large scale extinction in both ocean and land-based life forms. These changes can be explained on the basis of the very slow changes in forcing previously mentioned. As a basis of comparison, human civilization itself has only existed for about 10,000 years. The warming we are seeing today is occurring faster than at any time we know of in the history of our climate, and scientists cannot identify any natural forcing mechanism operating on such a fast time scale with such magnitude. The rates of increase in greenhouse gas concentrations, however, do provide a physical explanation for the observed temperature increases.

The very high confidence that human activity is responsible for warming comes from climate models. With climate models we can examine the impact of individual contributions to climate change—solar fluctuations, volcanoes, ozone fluctuations, greenhouse gases, and sulfate aerosols. Figure 4 compares Earth's temperature if only natural forcings were active with a temperature trace that includes anthropogenic forcings in addition to natural forcing. As you can see, the natural forcings alone cannot recreate the temperature graph of the past century, particularly the last 30 years.

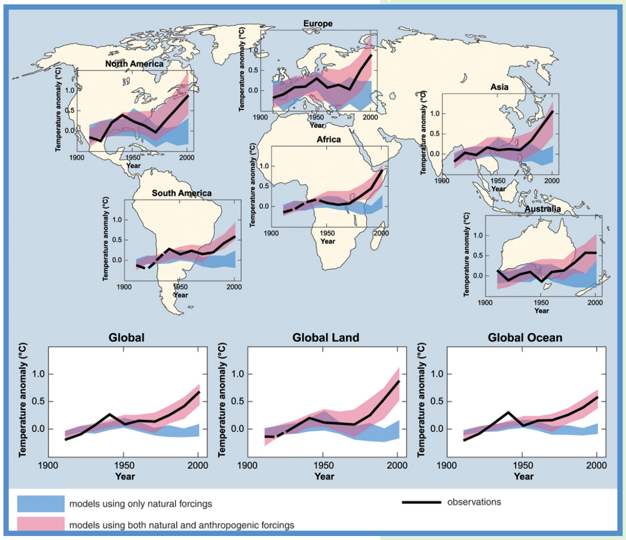


Figure 4. Temperature trends from 1900 to the present: global, land averaged, ocean averaged, and continental averaged. Black line represents observations. Blue band represents model simulations where only natural factors changing climate are included. Red band represents model simulations where human contributions (increased greenhouse gas concentrations and sulfates) in addition to natural factors are included. Observed temperature change of the late 20th Century cannot be explained on the basis of natural factors alone.

Humans and climate change

The very high confidence that human activity is responsible for warming comes from climate models and demonstrates that natural cycles alone cannot account for the temperature changes of the past century.

Part 2: Global warming's effects on Midwestern agricultural communities

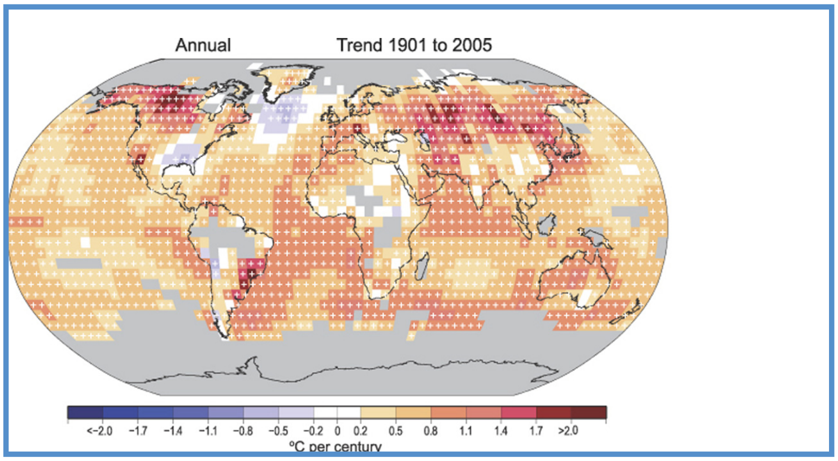


Figure 5. Global distribution of surface temperature changes from 1900 to the present.

2-1. Where is the warming occurring?

Temperature increases across the globe for the past century reveal that not all parts of the planet are warming at the same rate, or to the same degree. Figure 5 shows the temperature changes from the early 1900s to the present day. For most of the twentieth century and up to this point in the twenty-first, temperatures increased most in the highest latitudes, particularly in the northern hemisphere. A few places have actually experienced lower daily maximum summer temperatures in this period of time, and one of them is the central United States. This phenomenon is known by climate scientists as the "warming hole." A regional climate model indicates that daily maximum temperatures in this region will warm around one degree Celsius, or 1.8 degrees Fahrenheit, over the next 40 years while other parts of the US will warm more substantially. It is not yet known how long this "warming hole" trend will continue, or how slowly the warming will continue to be in the Corn Belt, but in any case, these changes likely are already having an effect on Midwestern agriculture and will continue to do so.

2-2. What do these changes mean in the short term for the Corn Belt?

In the Corn Belt, there has been an increase in daily maximum and daily minimum temperatures in winter and an increase in daily minimum temperatures in summer. The summer daily maximum temperatures, however, have decreases as previously described. These trends are likely to continue, except the trend toward more mild daily maxima in summer, which may eventually reverse.

These changes in temperature might seem pleasant to those who are not involved in agricultural production. But it means that pests and weeds that thrive in the southern hardiness zones but are ordinarily killed off by cold temperatures in the Corn Belt will begin to migrate northward, forcing producers to deal with new threats to their crops. In terms of risk to profitability for farmers, one area of concern is the increased probability of extreme events, such as more mild spring temperatures followed by a sudden cold snap like the April freeze of 2007.

The general rule of climate change at the global scale is that the wet areas will become wetter and the dry areas will become drier. Although there is less confidence in the data for changes in precipitation and atmospheric moisture at regional scales, it seems likely that recent trends toward higher annual precipitation in the Midwest will continue. Higher levels of atmospheric moisture also mean an increasing risk of overnight leaf wetness, which brings a greater threat of diseases like fungus and toxins.

With a warming climate, the recent trend toward an increased risk of extreme events will continue in our region. An increase in atmospheric moisture can lead to "gully washers" that enhance soil erosion and lead to crop losses, as well as floods that damage infrastructure in Midwestern towns and cities, as we saw throughout Iowa in early 2008. Although drought should always be treated as a normal feature of climate, an increase in extreme rainfall events also may bring longer periods without rain and thereby increase the probability of drought.

Not all of the near term changes are expected to be negative. In fact, higher concentrations of carbon dioxide may have a very small fertilizing effect on crops. Longer growing seasons, more precipitation, and fewer days with extreme heat are all good for Midwest agriculture. And there is also the possibility that the Midwest can see additional agricultural profits, at least in the short term, as farming regions elsewhere in the world suffer damages from a changing climate.

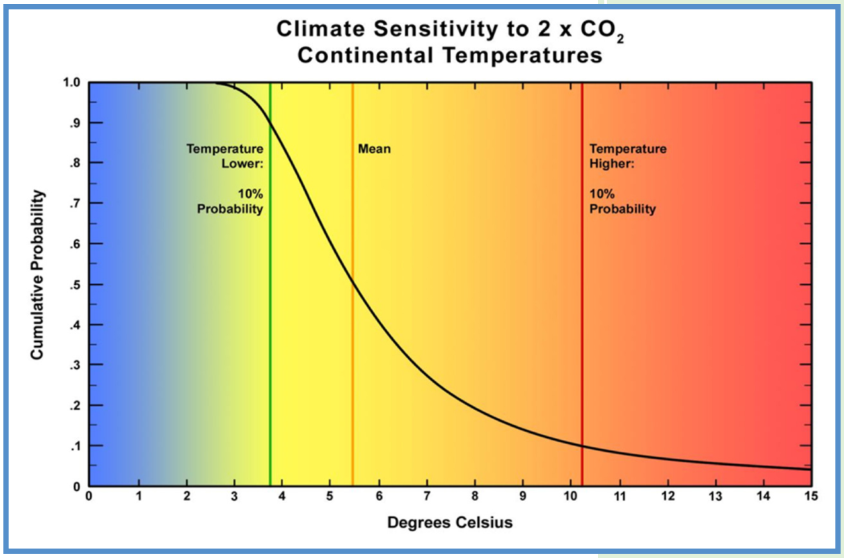
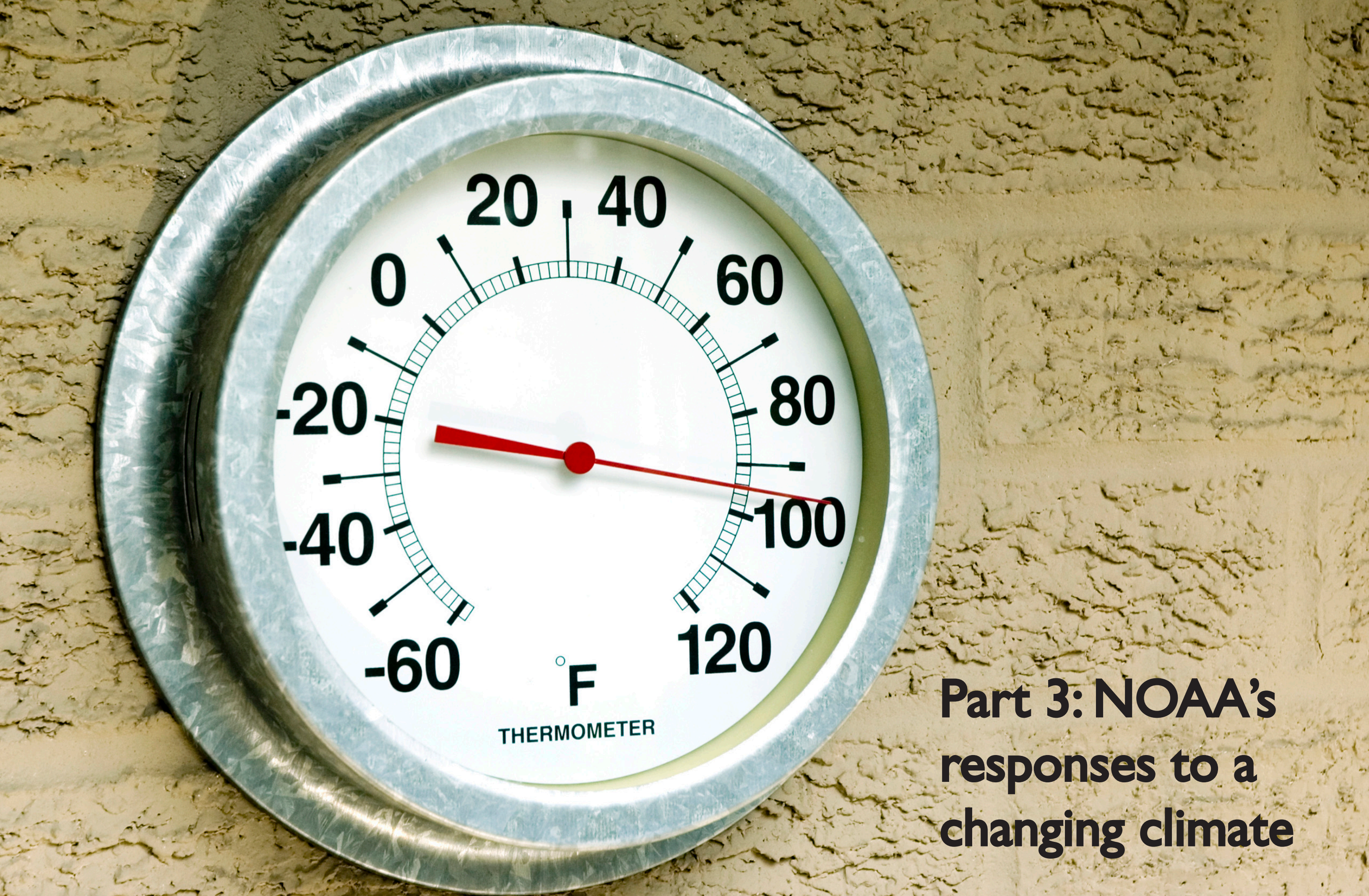


Figure 6. Climate sensitivity. Probability, given by climate models, that the average continental temperature under a doubling of atmospheric carbon dioxide will rise by a given amount. For example, the probability is 0.9 (9%) that the continental average temperature under a doubling of CO2 will rise 3.8°C (6.8°F) and a probability of 0.1 (10%) that it will rise 10.2°C (18.4°F).

When climate scientists talk about forecasts of any kind, from rainfall next week to temperatures at the end of the 21st century, they talk in terms of probabilities and percentages. Figure 6 shows global average temperature probabilities produced by a global climate model for a scenario with about twice the greenhouse gases we have in the atmosphere today. It is important to note that the temperatures are listed in terms of Celsius. Converted to Fahrenheit, the most likely scenario—an increase of 5.5 degrees Celsius—becomes an increase of 9.9 degrees Fahrenheit. It is also worth paying attention to the percentages on either side. There is a 10% likelihood that temperatures will have a lower rate of increase, around 3.75 degrees Celsius, or 6.75 degrees Fahrenheit, and an equal 10% likelihood that temperatures will rise by 10.25 degrees Celsius, or 18.45 degrees Fahrenheit. Just adding another 6.75 degrees F onto the hottest days of the year would increase the number of days per year that reach over 100 degrees. To get a sense of what that means for everyday life, we will use Iowa—the buckle on the Corn Belt—as a basis of comparison. Under that scenario, meaning if we're lucky, the climate of Iowa would be like that of northern Kansas. Under the most likely scenario, Iowa would have a climate like that of western Oklahoma—much hotter and drier than it is today. If we're extremely unlucky and we get that 10% chance of a higher temperature, Iowa would have a climate like that of western Texas—a desert. In all three scenarios, Iowa would be attempting to grow corn in much more arid climate than it has today at a time when water supplies are expected to be constrained. This means that if we do nothing at all for the next century to slow down the rate of global warming, growing corn in the Corn Belt will be a challenge. This scenario produced by global climate models does not include the possible impact of the "warming hole" suggested (at least for mid-century) by a regional climate model.



Part 3: NOAA's responses to a changing climate

3-1. How does NOAA gather weather and climate information?

One of the most common complaints about weather forecasting is that it is not always accurate. In fact, people are fond of saying, "How can you predict climate change over a period of decades when you can't even tell me what the weather will be like next week?"

There are a couple of responses to these statements. First of all, weather, as we mentioned before, is not the same as climate, and they are not calculated in quite the same way. Climate is the long term pattern of changes that can be observed, despite day to day fluctuations, over a period of decades or centuries or longer. Weather is the day to day fluctuations. And second of all, NOAA is rapidly increasing its accuracy in predicting both weather and climate through the ability to gather and process an ever-expanding amount of data. Of course, it is impossible to be completely accurate in predicting how a complex system responds with a wide range of possibilities. For example, when hurricanes come through the North Atlantic, they cannot say exactly where it will make landfall until less than 48 hours before it actually does. They give a probability range for the places it is most likely to make landfall. But their accuracy has improved greatly through the implementation of a variety of data-gathering mechanisms, each of which has a different response and communication time.

NOAA has many networks to observe the weather, from satellite to rain gauges on the ground. Two of the largest NOAA data collection systems are the Cooperative Observers Program (Coop) and the

Automated Surface Observing System (ASOS). The Coop network is a cooperative network of volunteers measuring many variables such as precipitation and temperatures on a daily basis. The ASOS is an automated observing network usually at airports. These networks are some of the most sophisticated and complex data-gathering tools available for both meteorologists and climatologists.

In addition to NOAA observations, other networks (sometimes referred to as mesonets) record meteorological variables. These are usually managed by non-NOAA groups and are important to weather prediction and monitoring. For example, precipitation information is gathered by the well established Community Cooperative Rain, Hail, and Snow Network, or CoCoRaHS

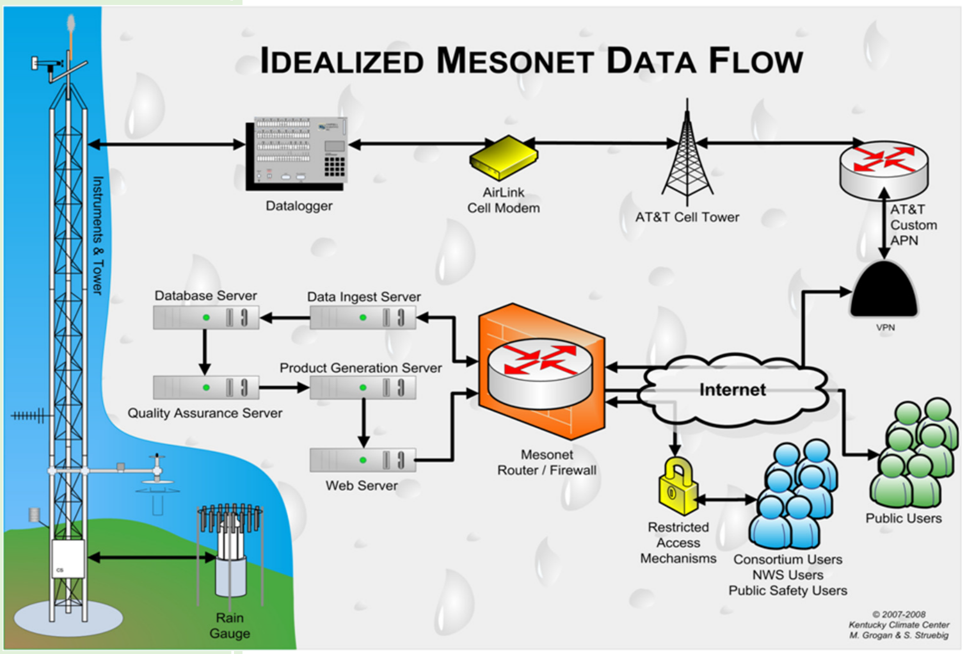


Figure 7. Modern weather information delivery systems acquire high-quality observations and perform quality assurance, data integration, and archive capabilities. Models are built to deliver user-tailored weather products and decision tools for a wide range of specific clients in near real time.

Network. It is a network of volunteers who are provided training and equipment by state climate offices and NOAA to report information about the amount and type of precipitation that falls throughout the region.

In addition to weather forecasts for the upcoming week or so, NOAA also creates climate outlooks from two weeks through one year based on climate information from models, a network of satellites and by using sea surface temperatures as indicators. These seasonal forecasts can be used to forecast weather patterns for the next month, or even into the next season, although with a longer time horizon comes greater uncertainty. Seasonal forecasts often rely on the current El Niño Southern Oscillation cycle (ENSO). In other words, based upon what is happening in the equatorial west Pacific, general predictions can be made about temperature and precipitation in the U.S.

3-2. How does NOAA know that the accuracy of its forecasts is improving?

NOAA is able to verify the improving accuracy of its forecasts by comparing past forecasts with actual observed temperature, precipitation, and other atmospheric conditions. Through this comparison of forecasts with observations, NOAA has been able to determine that the accuracy of their forecasts has been improving over time with the inclusion of newer technology and better integration of monitoring equipment, observer networks, and modeling software.

3-3. How can NOAA help producers reduce risks to profitability?

NOAA wants to be as useful and reliable for producers as possible to help decision makers understand and prepare for the weather and climate they are going to face in the near and long term. NOAA produces information that can be used in various types of modeling and decisional tools. Improvements in the accuracy of forecasts and precipitation monitoring is already helping farmers to be able to irrigate more accurately through systems like KanSched, a seasonal irrigation scheduling tool that can be downloaded through the Kansas State University cooperative extension website, used to help farmers better anticipate what their upcoming watering needs will be and respond accordingly.

Better climate forecasting is also helping farmers decide what to plant in a given season, as well as how many seeds to plant in each field. Sometimes for corn farmers it's a relatively simple question of which hybrid to choose for a particular season. Other times the choices they face are more difficult. Wet, waterlogged soils are not good for growing corn, so if farmers can anticipate a wet growing season they may want to opt for soybeans that year instead. Extremely dry weather is also not good for corn, so they might choose to grow a dry climate crop for a season, like sunflowers or sorghum. Plant population is one area where farmers can either lose a lot of money on sunk seed costs or a lot of opportunity by not seeding enough, so anticipating the growing season can be a key factor in knowing how many seeds to plant.

Knowing what weather is coming can also be helpful in knowing when to apply nitrogen, even though there has not been strong correlation between advance knowledge of weather conditions and response in the volume of nitrogen applied. Farmers may avoid loss through excessive nitrogen application in years with optimal temperature and rainfall where excess nitrogen is not needed for high yields.

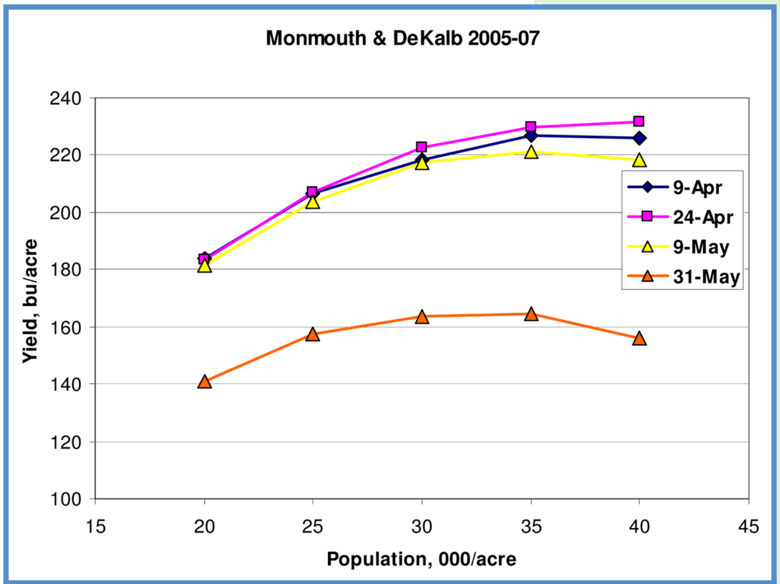


Figure 8. Dependence of corn yield on plant population and planting date at two Illinois locations. Also shown is typical ear size for various plant populations. As long as ears are getting smaller more slowly than plant population increases, it pays to plant higher populations.

Part 4: The national climate service

4-1. What is the national climate service?

In 2008, the 110th Congress put forth a proposal for a new federal program called the national climate service, to be administered by NOAA. The National Climate Service would be a multi-federal agency, a multi-state and academic endeavor that would encompass the many efforts currently underway across the United States to deliver pertinent information on all aspects of climate. One purpose of a national climate service would be to understand and interpret climate change information pertinent to the immediate future. This information would be used to help communities adapt to the climate change we are currently facing as a result of the carbon dioxide already in the atmosphere and projections into the future.

4-2. How could a national climate service be of use to Midwestern agricultural producers?

NOAA is currently in the process of putting together proposals for the type of programs they could offer through a national climate service. In fact, this report is a part of the beginning of dialogue with communities around the country that rely heavily on weather and climate information to determine what kinds of information about a changing climate would be most useful. NOAA is actively seeking information from many sectors including agriculture about what kinds of information they need to help them reduce risks and how much advance notice they need for the information to be able to make much of a difference.

Part 5: Climate change mitigation and adaptation

5-1. Midwestern agricultural emissions and reductions

The Midwest is an enormous contributor to greenhouse gas emissions. Collectively, Midwestern states would be the 7th largest emitter of greenhouse gases in the world. Slowing climate change and preventing the serious consequences of global warming will require participation from all sectors through a combination of government legislation and investment in new technologies. The Midwestern agricultural industry is already beginning to look at possibilities for growth in low carbon energy, and is in some cases leading the nation in terms of investment in low carbon energy and fuels. Various initiatives are underway to regulate greenhouse gases through a cap and trade program that would place a strict limit on the amount of allowable greenhouse gas emissions for the all or part of the U.S. economy (the "cap" portion). These include the Midwestern Greenhouse Gas Reduction Accord, other regional initiatives, and various state and federal proposals. A cap and trade program would also create a carbon market that would allow private companies, including producers in the agricultural sector, to generate and sell credits for the amount of greenhouse gas reductions they are able to make (the "trade" portion). A cap and trade system ensures both that annual targets for greenhouse gas reduction are met by the economy as a whole and that these reductions are made at the lowest possible cost to companies and consumers.

5-2. How could producers participate in a cap and trade system?

Right now, it is uncertain whether the agricultural sector will be included under a cap and trade system because the emissions from individual sources are too small and administrative costs too high. Even if agricultural producers are not included right away as mandatory participants in a cap and trade system, they may still have the opportunity to sell carbon offsets, if offsets are included as an acceptable way for firms to meet their reduction requirements. Carbon offsets would be subject to strict transparency rules, and would have to be permanent, verifiable, and not be something that producers would have done anyway without being paid for it—otherwise there is no guarantee of an actual net greenhouse gas reduction. Controlling methane and nitrogen oxide emissions, reforestation, capturing and sequestering carbon dioxide at ethanol plants and developing low carbon renewable energy like biogas from an anaerobic digester are all ways that producers could potentially generate and sell carbon offsets.

5-3. What other ways could producers reduce carbon emissions?

The Midwest has great potential to provide low carbon energy for the nation and world through its agricultural producers and other related industries. We have a world class wind resource that states like Iowa and North Dakota are already taking advantage of, and farmers throughout the region are benefiting from the increased revenue they receive through the siting and part ownership of wind turbines. Many components of wind turbines are already manufactured in the Midwest, including blades, towers, and gearboxes. Many Midwestern firms also install and operate wind turbines. But more components, including the generators themselves, could be made in the Midwest, and the Midwest could benefit from more exporting of components. But the development of turbine manufacturers is one of the ways in which our region could revive the economies of our Rust Belt states—and also provide wind turbines at lower shipping costs. We also have a world-class biomass resource that can be harnessed using today's technology and used efficiently for heat and electricity production in small-scale combined heat and power (CHP) plants, in combination with new district heating systems, to produce electricity and heat for homes and business, as well as "fuel" for electric vehicles. In addition to today's technology, researchers at our region's universities are working on ways to make liquid fuels at a low cost from biomass. Farmers could sell any biomass they do not need for fertilizer or soil protection for the production of energy.

5-4. What about corn ethanol?

Corn ethanol has been widely accepted as a substitute for gasoline that could help combat global warming. Recent studies about the direct life cycle greenhouse gas emissions of corn ethanol show roughly a 60% reduction of greenhouse gases over gasoline. However, the major unknown variable for corn ethanol's ability to slow climate change is indirect land use change. Indirect land use change happens as a result of combining agricultural markets with liquid fuel markets, which causes the price of agricultural commodities to rise alongside oil prices. The connection between biofuels policy and commodity markets also points to a connection to conversion of native ecosystems in other countries to meet increased aggregate commodity demand. This land conversion results in a release of carbon dioxide that, according to one study, cancels out any reductions that could be made by substituting corn ethanol for gasoline. There will be considerable debate about this issue as the science evolves and policymakers determine the best way to address potential indirect impacts that occur beyond our borders. Meanwhile, the Midwest will continue to work to develop and commercialize advanced biofuels from non-food crops while investing in efficiency improvements that reduce the greenhouse gas emissions of the existing industry.

5-5. How can we prevent damage to our economy, infrastructure, and human health from the greenhouse gases already in the atmosphere?

Even if we could somehow stop all the emissions of greenhouse gases tomorrow, there is already so much in the atmosphere that we would not be able to reverse global warming until at least the middle of the twenty-first century. So the climate will continue to change, despite our best efforts, for another fifty years. It is of paramount importance to significantly reduce our greenhouse gas emissions by midcentury, but we will also need to anticipate the changes that will take place in our climate over the next 50 years and help communities to plan for and adapt to them. A national climate service could serve an important role in creating an adaptation strategy for our region.

Adaptation is a concept that has received little attention until recently, but we must begin a national dialogue about it in order to adequately plan for the changes we are already beginning to see. We need to look at our infrastructure investments and develop plans to prevent hazards—such as an increasing number of floods, or a much moister or drier atmosphere—from becoming disasters. Regional agricultural producers must also take a proactive role in seeking information about the ways climate will change and take these changes into account when making investment decisions for the next half-century. The aforementioned cap and trade initiatives will likely include funding for adaptation, and once we begin this national dialogue, we can start to identify the most critical areas to apply this funding.

Part 6: Conclusion

The science of climate change is clear—global warming is occurring and is causing large-scale changes in the planet's climate systems. Human influence, particularly the emission of greenhouse gases, is the major driving factor behind these changes. It is also clear that although the Midwest has not experienced negative effects of climate change, agricultural producers in our region eventually will be coping with a wider range of its consequences.

More severe consequences of climate change can be avoided by reducing as rapidly as possible the amount of greenhouse gases emitted into the atmosphere. But even under an aggressive reduction scenario, there are already enough greenhouse gases in the atmosphere to present risks to Midwest agricultural profitability.

The Midwest is a large emitter of greenhouse gases. Leadership from government and industry will be needed to help our region curb its greenhouse gas emissions by transitioning to systems of low carbon energy, as well as anticipate the climate changes that will take place for the next half century. This leadership must extend beyond caps on emissions and the development of carbon markets and new sources of energy to providing the information communities and agricultural producers will need to adapt.

NOAA can play an important leadership role by providing agricultural producers with the information they need to anticipate and prepare for potential risks to profitability. They have extended an open invitation to producers to provide them with feedback about what specific types of information they need the most and in what time frame they will need it in order to be of use to them.

Agricultural producers and others in Midwestern agricultural communities should become more aware of the nature

and consequences of climate change. Adapting to climate change presents both opportunities and challenges. International and national strategies for mitigating long-term effects of climate change also have implications for this region. Rapid advances in technology and additional revenue streams, such as selling credits and offsets in a mandatory carbon markets or part ownership of wind farms, provide new opportunities unavailable even 10 years ago. There is urgent need to ensure that near-term and long-term policies take into account the natural resources of our region—high-quality soils, abundant fresh water, and a favorable climate. This is best done by ensuring that full use is made of the best available science as climate changes.
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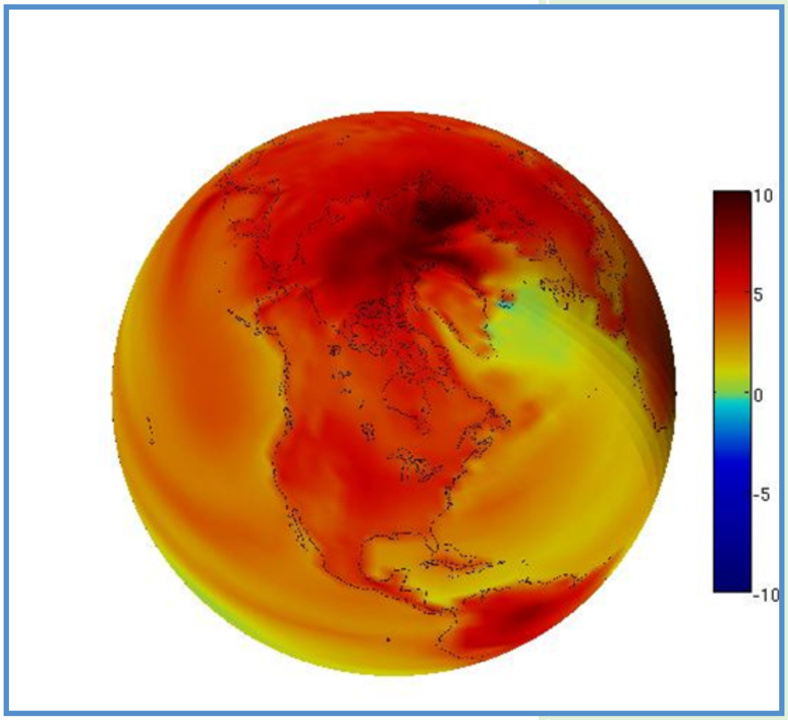

Figure 9. By 2100 Earth will warm by by approximately 5oC (9oF) (more at high latitudes and over continents and less over oceans) if emissions of greenhouse gases continue to rise at current rates.

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